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Thermal memory influence on the thermoconducting component of indirect photoacoustic response

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Abstract

In this paper, a model of the thermoconducting component of the indirect photoacoustic (PA) response is derived that includes thermal memory properties of the examined material and its fluid environment. A comparison is made between the derived model and the classic one, which neglects the influence of thermal memory. It has been shown that, at modulation frequencies lower than a certain boundary frequency of the light source, these models tend to overlap, while at higher frequencies, noticeable differences occur. The boundary frequency depends on heat propagation velocity through the sample and its thickness. This observation limits the validity domain of previous models to a range lower than the boundary frequency, offering, at the same time, the possibility of obtaining thermal memory properties using PA effects at frequencies above it.

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(Some figures may appear in colour only in the online journal)

1. Introduction

When an intensity-modulated laser beam impinges on a solid in an enclosed cell, an acoustic signal is produced within the cell. This effect, known as the indirect photoacoustic (PA) effect, is the basis of a set of experimental PA techniques that have been, over the last three decades, developed and applied for nondestructive evaluation of optical, thermal, elastic, electronic and other related physical properties of crystalline and semi-crystalline solids [1–9].

The transformation of incident electromagnetic energy into acoustic energy occurs through heat. The interaction between the laser beam and matter causes partial absorption of the incident energy. Nonradiative de-excitation processes convert a certain portion of the light absorbed by the matter (or all of it) into heat. This optically generated heat causes perturbation of the thermal state of the sample, causing the propagation of thermal, acoustic and plasma waves across it, consequently changing the mean sample temperature, causing

the appearance of a thermal gradient inside the sample as well as normal to the side of the greatest dimension and heat flow from the sample to the surrounding gas. The first and the second phenomenon give rise to an acoustic signal in the gas through thermal expansion and thermoelastic bending of the sample, respectively. The third process contributes to the acoustic signal by forming a thermal piston in the gas column of the cell. Only a relatively thin layer of air, adjacent to the surface of the solid, responds thermally to the heat flow from the solid to the surrounding air. This boundary layer of air can, thus, be regarded as a vibratory piston, creating an acoustic signal, and representing the thermoconducting component of a PA signal [1, 9].

A quantitative understanding of the thermoconducting component of the PA response was first given by Rosencwaig and Gersho (the thermal piston model) [1]. Their theory is based on classical heat conduction theory, excluding the influence of thermal memory. However, we have recently shown that thermal memory can significantly affect

